BASQUE CENTRE FOR CLIMATE CHANGE
Klima Aldaketa Ikergai

Bayesian Networks Seminar

Elena Pérez-Miñana, BC3

SUMMARY

Probabilistic models based on directed acyclic graphs have a long and rich tradition, beginning with work by geneticist Sewall Wright in the 1920s. Within statistics these are known as directed graphical models; within cognitive science and AI, such models are known as Bayesian Networks. The name honours Rev . Bayes (1702-1761), whose rule for updating probabilities in the light of new evidence is the foundation of the approach.

Judeas Pearl

EUSKO JAURLARITZA GOBIERNO VASCO
HEZKUNTZA, UNIBERTSITATE ETA IKERKETA SAILA
INGURUMEN, LURRALDE PLANGINTZA, NEKAZARITZA ETA ARRANTZA SAILA
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CONTENT

- Introduction
- Defining the structure of a BN
- Building and eliciting NPTs
- Learning a BN
- BNs for GHG estimation in Agriculture

Introduction – Problems with Conventional Statistics

- Problems with “conventional” statistics
  - Limitations of the Normal distribution
  - Dubious relations: beware of correlations and their significance values (p-values)
  - Regression analysis – its failings
  - Using averages
  - Simpson’s paradox
- Need for causal/explanatory models
  - Risk assessment
    - For risk assessment and management, the regression model provides no explanatory power at all
  - Correlation is not causation
  - Limitations of the impact-based risk measure (Armageddon)
    - Conventional risk equation: Risk = Prob(Risk)*Impact(Risk)

Measuring uncertainty

- Probability is the manner in which uncertainty is quantified
- Humans deal with a great variety of uncertain events, but all can be located on the scale
  - Events where we appear to have a good understanding of the uncertainty
    - the next toss of a coin will be a head
  - Events where we have a poor understanding
    - Athletic Bilbao will win the next “Copa del Rey”
  - Unknown events
    - The city of Bilbao will suffer a major flood event in the next couple of years
    - Bárcenas is the cheat the media currently claims him to be (246,000 results in Google)
      - http://news.xinhuanet.com/english/world/2013-07/23/c_132567058.htm
      - http://www.ft.com/intl/cms/s/0/cbeb326c-f20a-11e2-afd8-00144feabdc0.html#axzz2ZuCrPXcB

- Any approach to quantifying uncertainty must
  - Handle all uncertain events in a consistent way
  - Enable the user to revise their beliefs in the presence of new evidence

Basics of Probability

- Probability is a measure that must satisfy 4 fundamental axioms
- Axioms
  - The probability of any event is a number between 0 and 1
  - The probability of the exhaustive event E is 1
  - For mutually exclusive events, the probability of either event happening is the sum of the probabilities of the individual events
- Theorems
  - The Probability of the complement of an event E is equal to (1 - P(E))
  - The Probability distribution for an experiment is the assignment of probability values to each of its possible states
  - The Probability of an event E is the sum of the probabilities of the elementary events that make up E

Basics of Probability-(Theorems&Definitions)

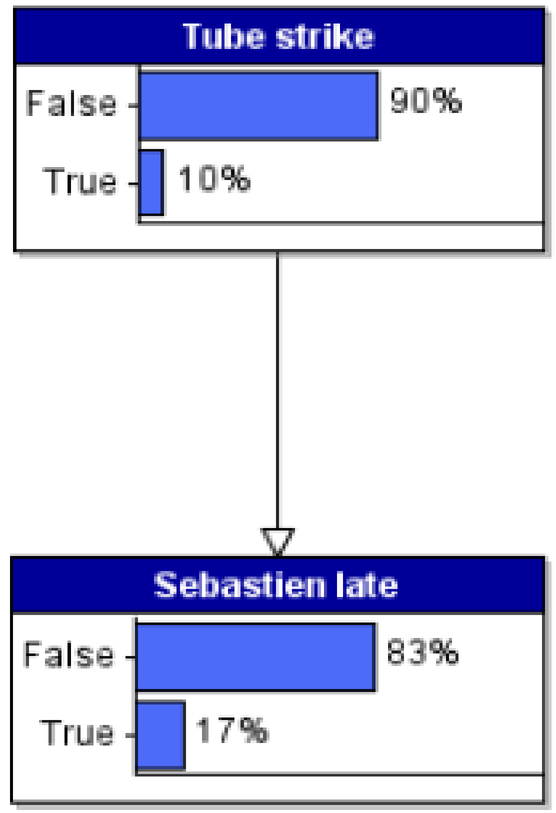
- The Probability of independent events
  - $P(A \cap B) = P(A) \times P(B)$
- The Probability of events not necessarily independent
  - $P(A \cap B) = P(A) \times P(B|A)$
  - $P(B|A) = (P(A \cap B)/P(A))$
- Fundamental rule of Conditional Probability
  - $P(B|A) = (P(A,B)/P(A))$
- Marginalization of A over B: $\mathrm{P(A)} = \sum_B P(A|B) * P(B)$
- The probability distribution for a variable is the assignment of probability values to each of its possible states (elementary events)
- All Probabilities are conditional
  - If the same context K is assumed throughout an analysis then the probability of an event A occurring in context K is written simply as P(A)

Bayes' Theorem and Probabilistic reasoning

- Probabilistic reasoning
  - Start with a hypothesis H, for which there is a belief P(H): prior belief of H
  - Use evidence E, about H to revise the belief about H in the light of E, that is P(H|E) which corresponds to the posterior belief of H
- **Bayes theorem**
  - **$P(H|E) = (P(E|H) \times P(H))/P(E)$**
  - Its validity can be demonstrated by using the axioms

Bayes Theorem

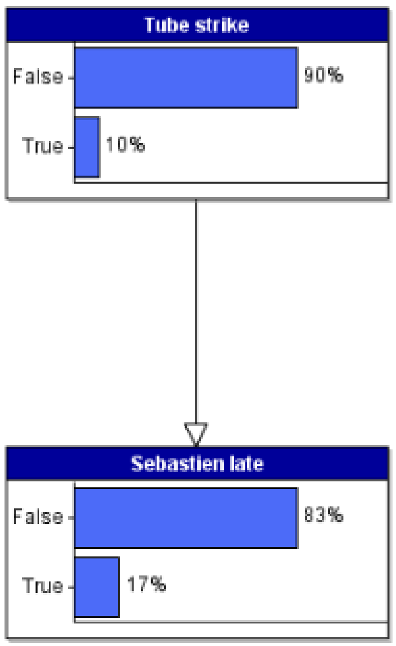
- adaptive and flexible
- makes better use of new evidence to update the original beliefs. The evidence is “propagated through the network”. This can be done in both directions (forward or backward)
- Bayes’ theorem is simply a method for defining and manipulating conditional probabilities and it provides a natural way to compute them
- It helps to avoid common fallacies of probabilistic reasoning

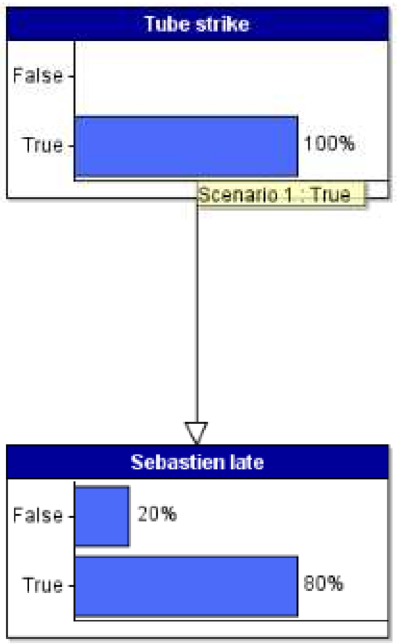


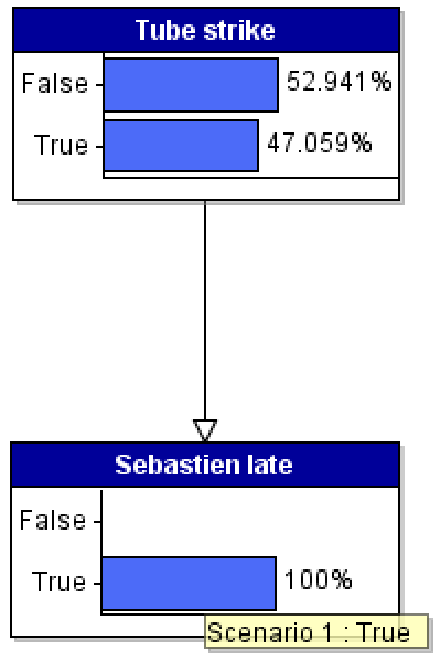
Possible computations with a simple 2-node BN

$$P(S=true) = P(S=true \mid T=true) * P(T=true) + P(S=true \mid T=false) * P(T=false)$$
$$= 0.8*0.1 + 0.1*0.9$$
$$= 0.17$$

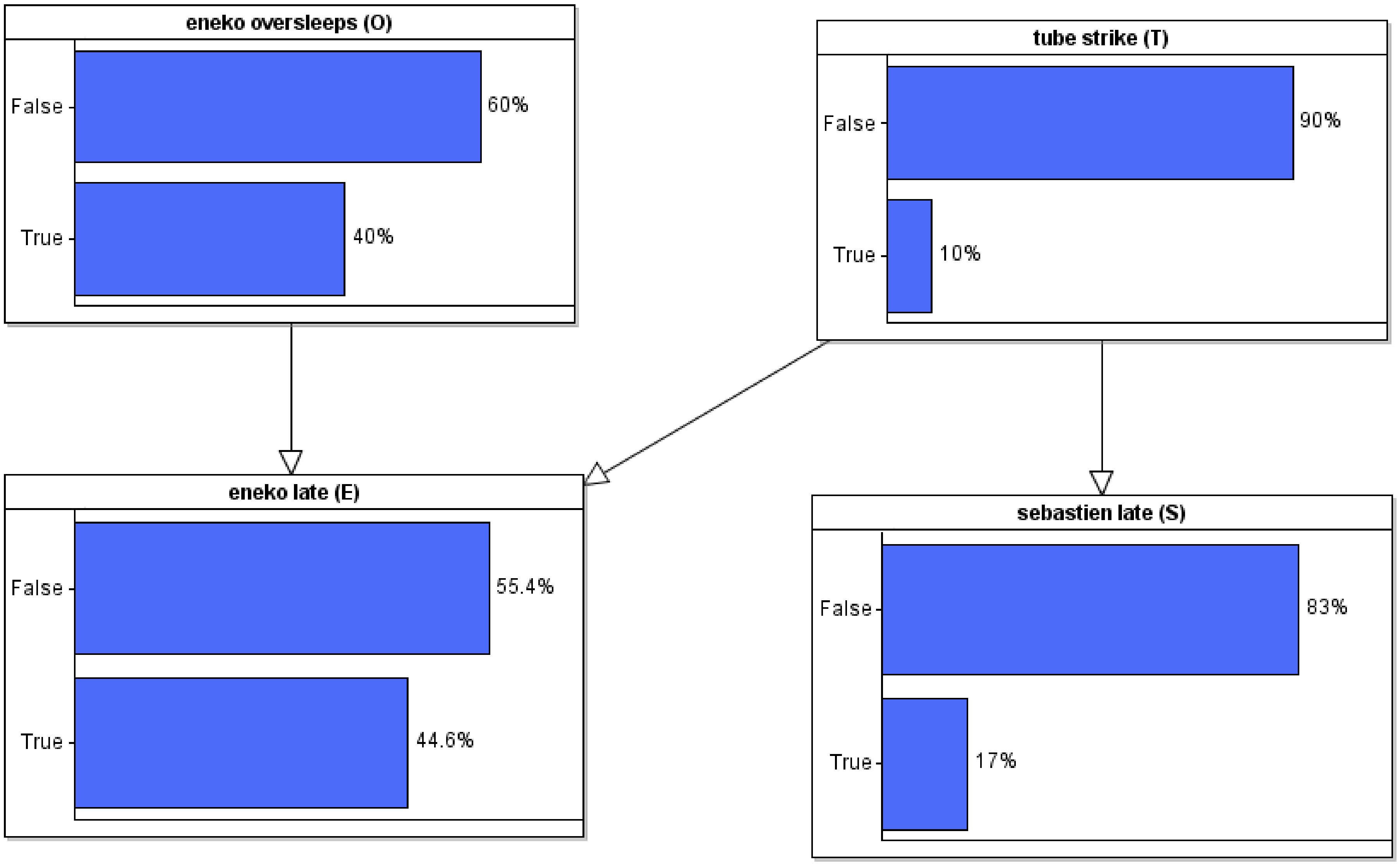
$$P(T=true \mid S=true) =$$
$$= P(S=true \mid T=true) * P(T=true) / P(S=true)$$
$$= (0.8*0.1)/0.17$$
$$= 0.47$$







Accounting for multiple causes and events

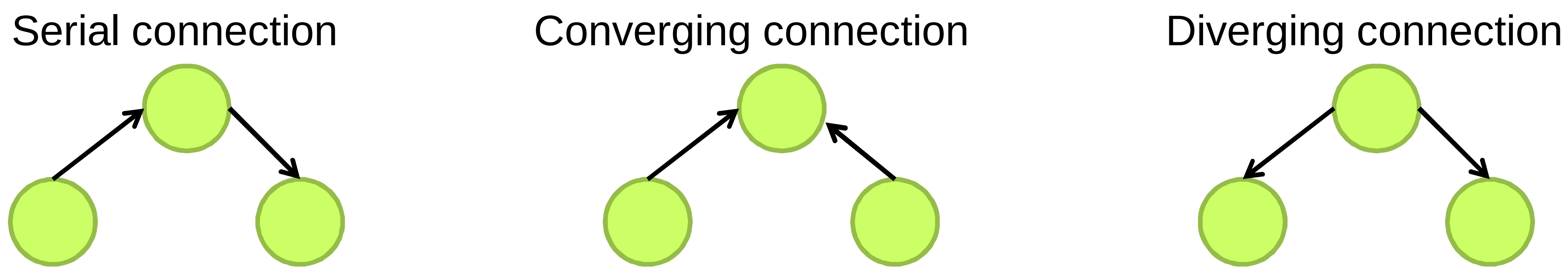


Benefits of using BN

- Explicitly model causal factors
- Reason from effect to cause and vice versa
- Reduce the burden of parameter acquisition
  - A BN requires fewer probability values and parameters than a full joint probability model
- Overrun previous beliefs in the light of new evidence
- Make predictions with incomplete data
- Combine diverse types of evidence including both subjective beliefs and objective data
- Arrive at decisions based on visible, auditable reasoning
- The graphical feature is telling the user which variables are NOT linked, and hence captures the user's assumptions on which pair of variables are not directly dependent

Formal definition of a BN

- A BN is an explicit description of the direct dependencies between a set of variables. The description comes in the form of a directed graph and a set of NPTs
  - Directed graph is the topology or structure of the BN
  - NPT for each node.
    - Child node C: the probability distribution of C given the set of parents of C
    - Root node R: the NPT of R is the probability distribution of R
- Structural properties
  - In BNs the process of determining what evidence will update which node is determined by the conditional dependency structure



Propagating information in BN

- For a complex BN, the calculations are daunting/impossible to do manually
- No computationally efficient solution for BN calculation is known that will work in all cases
- In late 1980s things changed thanks to research completed by pioneers such as Lauritzen, Spiegelhalter, Pearl
  - They published algorithms that provided efficient propagation for a large class of BN models
  - The efficiency lies in taking advantage of the BN structure (variable elimination)

Steps in building a BN model

- Identify the set of variables that are relevant to the problem
- Create a node corresponding to each of the variables identified
- Identify the set of states for each variable and subsequently specify the states for each node
- Identify the variables that require direct linking
  - Identify the causal inference and select the correct edge directions
  - Mathematically cause to effect and effect to cause are equivalent
- For each node in the BN build the NPT

Use idioms (Fenton & Neil 2012)

- Idioms (webster dictionary): the syntactical or structural form peculiar to any language, the genius or cast of a language.
  - In Agenarisk, they refer to BN fragments that represent very generic types of uncertain reasoning.
  - the idiom is not a BN as such, but simply the graphical part of one

- There are 4 especially common idioms
  - **Cause consequence idiom:** models the uncertainty of a causal process with observable consequence
  - **Measurement idiom**: models the uncertainty about the accuracy of any type of measurement
  - **Definitional/synthesis idiom**: models the synthesis or combination of many nodes into one node for the purpose of organizing the BN. Also models the deterministic or uncertain definitions between variables
  - **Induction idiom**: models the uncertainty related to inductive reasoning based on populations of similar or exchangeable members

Benefits of using idioms

- Helps compartmentalize the BN construction process
- Act as a library of patterns for the BN development process
- Encourages reuse and is more productive
- An idiom instantiation is an idiom made concrete for a particular problem, by using meaningful node labels

Building the network nodes' NPT

- Manually
  - Small problems with fairly well-known uncertainties
  - Discrete nodes, continues nodes if the BN architecture consists of measurement idioms
  - Hold workshops with stakeholders
  - Review the literature
- Using learning algorithms
  - Learn the NPTs from data
  - Learn the network architecture and the NPTs

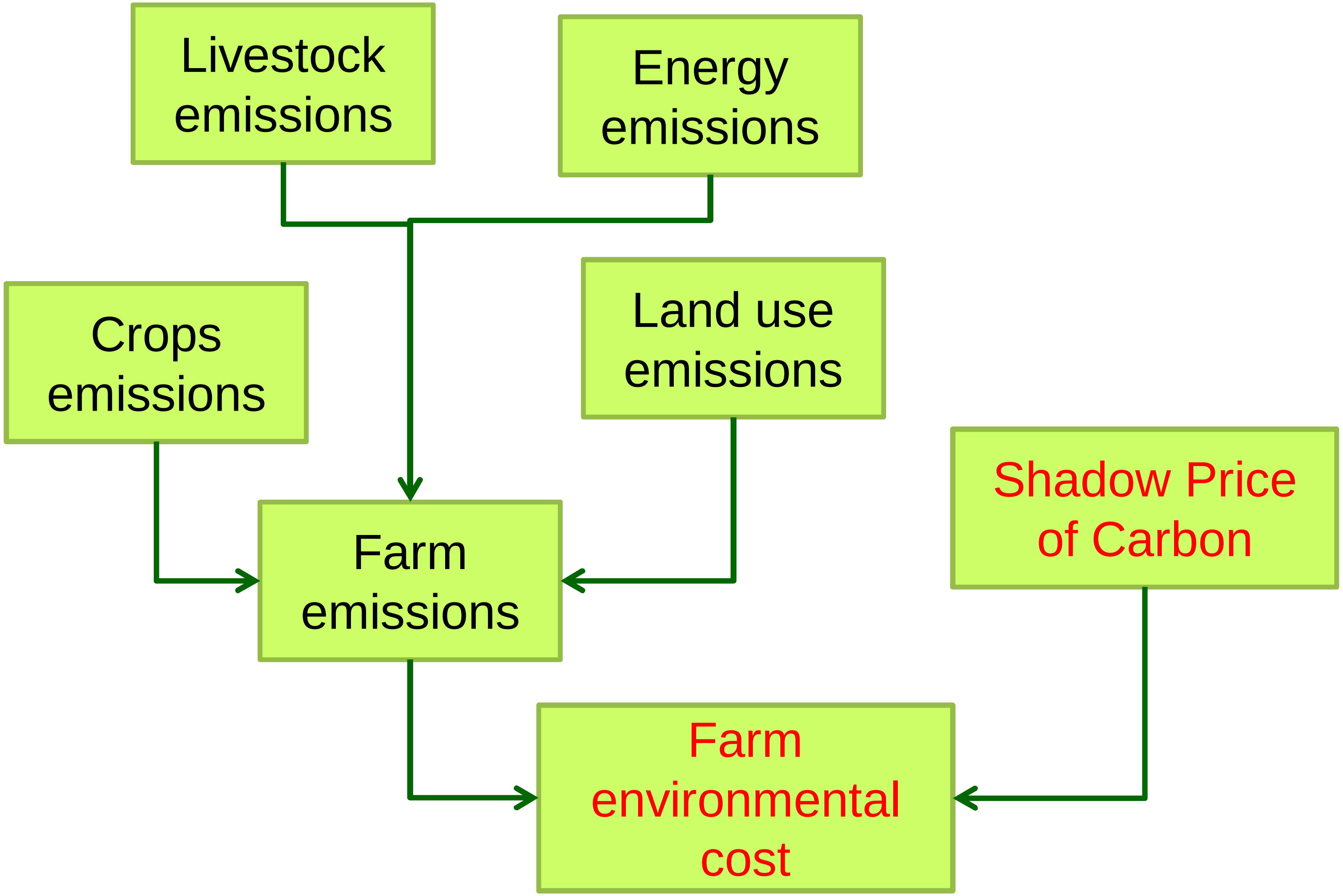
Bayesian **N**etworks to support **G**HG Emission reduction in the **A**gricultural **S**ector

BaNGAS

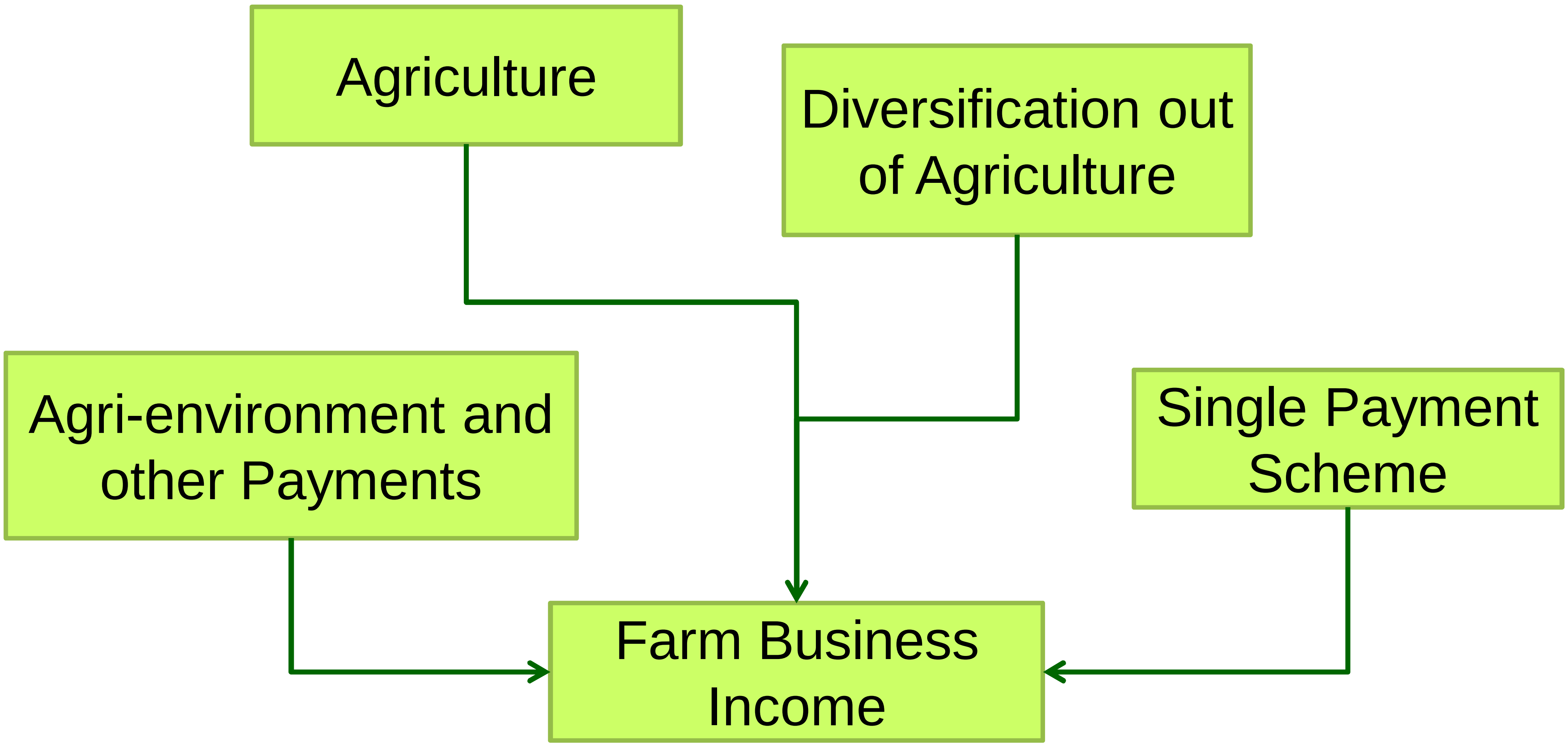
Why attempt the farmers' GHG estimation problem?

- There are a number of estimation mechanisms around but most of them are of a deterministic nature and don't target the agricultural sector
  - CALM from the CLA generates a number and provides very generic suggestions on how to proceed to reduce them.
  - The National atmospheric emissions inventory are too coarse (only estimates emissions at the economic sector level)
  - Other carbon calculators are not targeted at farmers, and reviewing the IPCC guidelines, it is likely that a one solution fits all does not exist

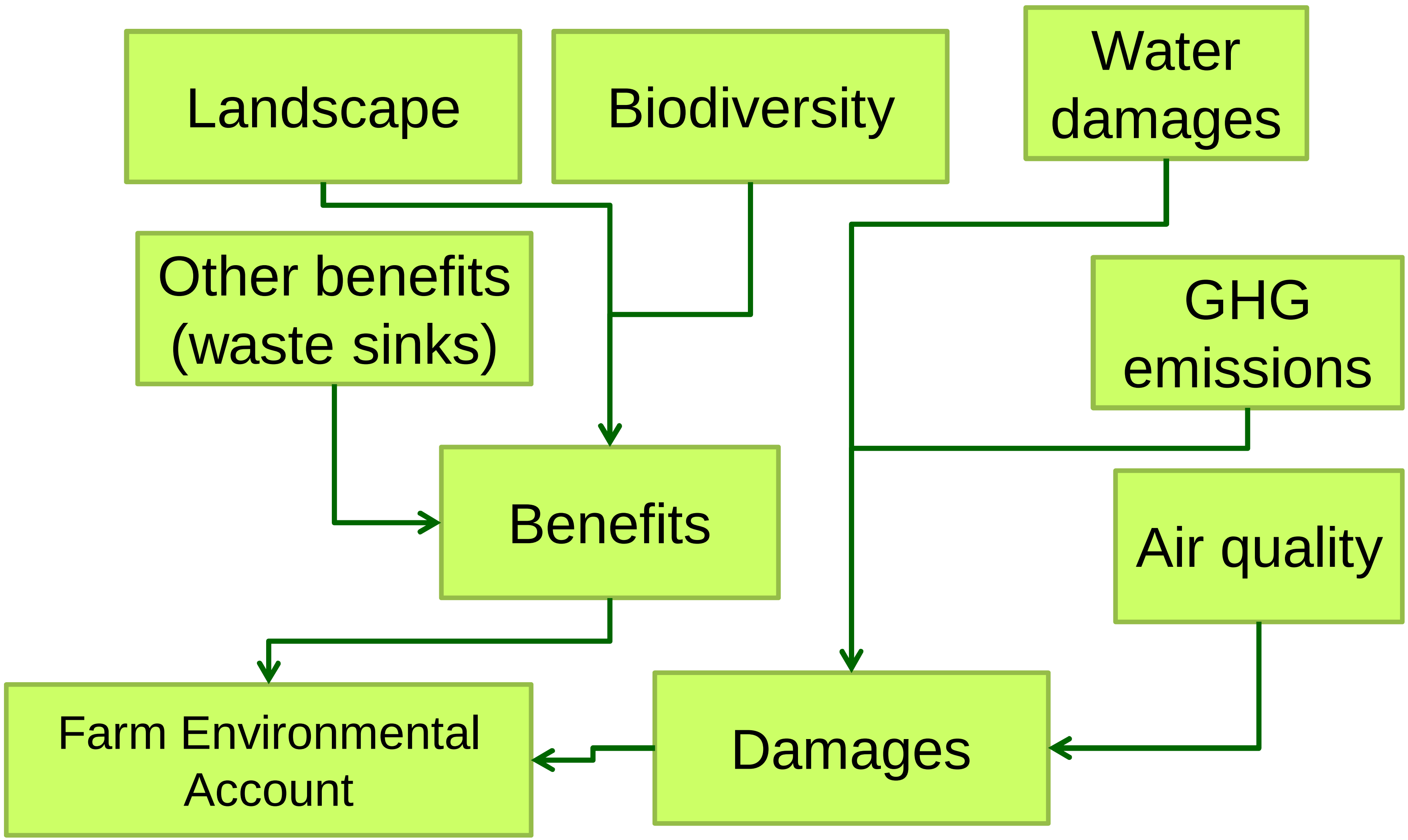
Top Level BN UK Farm GHGe estimation



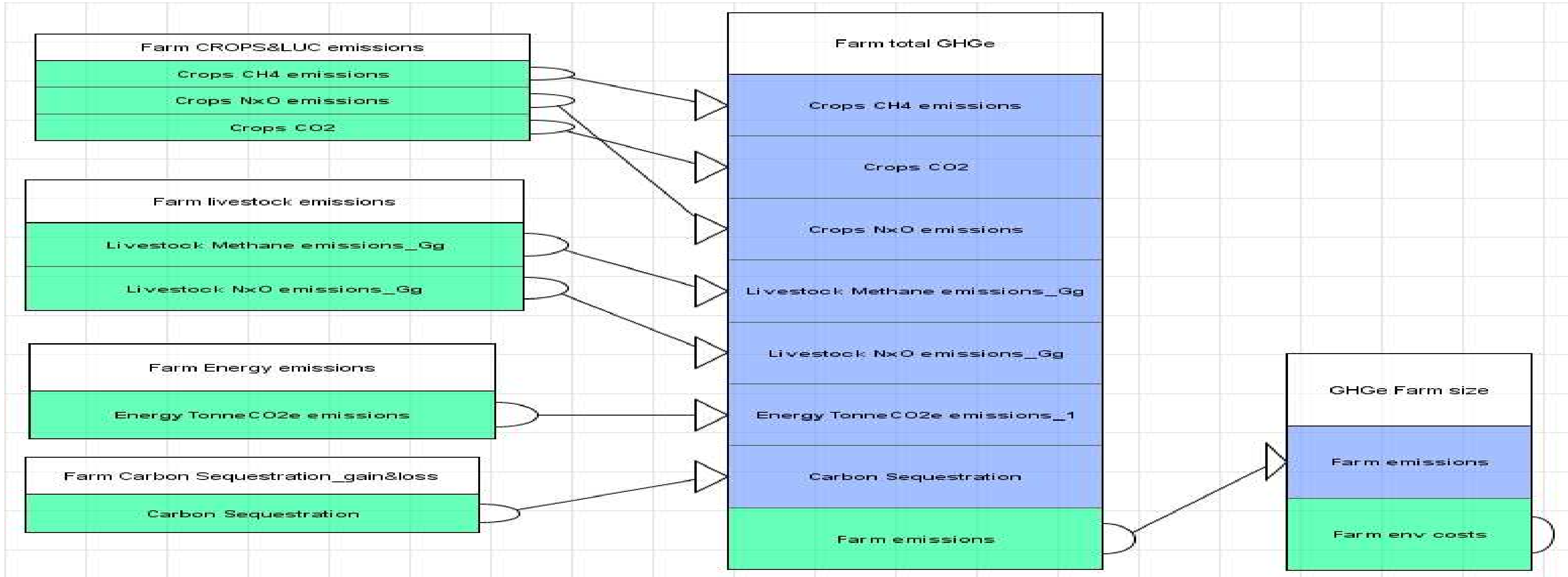
Top Level BN UK Farm's account



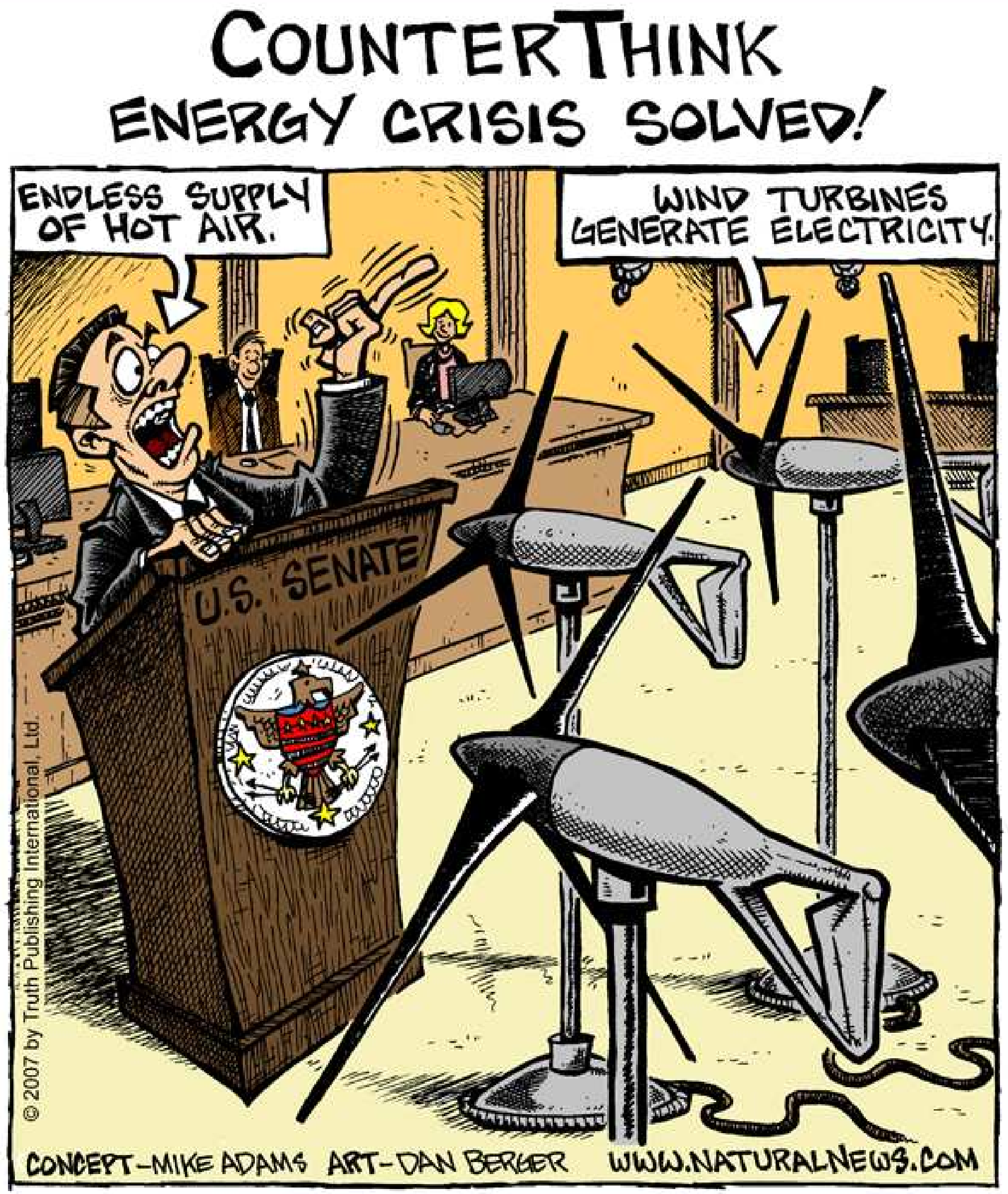
Top Level BN UK Farm's environmental account



Top Level BN architecture in AgenaRisk



THANK YOU!!
ESKERRIK ASKO!!!
GRAZIE!!
MERCI BIEN!!!
OBRIGADO!!
GRACIAS!!!



For more information

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